# NASA's Mission Operations and Communications Services

**This Description applies only to proposals in response to NASA's Announcement of Opportunity for Discovery Missions**

**AO 00-OSS-xx**

**May 2000**

# 1.0 INTRODUCTION

This document is intended to assist in the preparation of proposals in response to the Announcement of Opportunity (AO), AO-00-OSS-X issued by NASA's Office of Space Science (OSS) for Discovery Missions. NASA provides many operations and communications services that are available for NASA missions. The use of these services will incur costs to the user and estimates for these costs need to be included in proposals submitted under this AO. To facilitate proposal preparation, proposers are encouraged to read this appendix and contact the individuals named in Section 1.5 below.

## 1.1 Costing Policy

As a matter of policy, NASA will include estimated costs for mission operations and communications services, as well as an assessment of key parameters for mission operations, in the evaluation and selection processes for all Earth-orbiting and deep space missions. The OSS and the Space Operations Management Office (SOMO), are implementing this policy:

- in anticipation of formal NASA-wide full-cost accounting,
- to better manage our currently oversubscribed communications resources,
- to encourage tradeoffs between on-board processing and storage vs. communications requirements, and
- to encourage proposers to design hardware and operations systems which minimize life cycle costs while accomplishing the highest-priority science objectives.

## 1.2 Choice of Service Providers

Proposers are free to use all, some, or none of the NASA-provided services described below. Regardless of their choice, the proposal must include a rationale for the level of communications and mission services proposed and the costs of these services. Required services should be identified irrespective of the provider. Key communications and mission services parameters are listed below.

As a matter of policy, proposers should be prepared during Phase B to support tradeoff studies with the OSS and SOMO on the use of NASA-provided services versus proposed alternatives. In general, NASA-provided services should be employed whenever they meet mission objectives at a cost that is less than or equal to any proposed alternatives.

The Deep Space Network (DSN) is available for use by Discovery missions. All Discovery missions selected to date have employed or intend to employ the DSN as primary means of communicating with the spacecraft in flight. However, it is important to note that Discovery missions are not required to use the DSN.

### 1.3 Responsible Organizations

SOMO is responsible for the functional management of most NASA space operations facilities. SOMO is the NASA program manager for the Deep Space Network (DSN), other NASA Ground Network (GN) stations, the Tracking and Data Relay Satellite System (TDRSS), the NASA Information Services Network, and certain mission operations facilities located at NASA centers.

The Telecommunications and Mission Operations Directorate (TMOD) at the Jet Propulsion Laboratory (JPL) is the executive agent for the operations and engineering of the DSN and provides the technical expertise needed for flight projects to use the DSN. This expertise includes communications formats, antenna capabilities and performance limits, scheduling, loading and other operations considerations, and, in particular, maintaining the cost algorithm for employing the DSN. In addition, TMOD develops, maintains and employs a set of tools and services known as the Advanced Multi-Mission Operations System (AMMOS) for working with the DSN.

### 1.4 SOMO Service Categories

SOMO has moved from a facilities-based support approach to one based upon standard services. Standard services are described in the *SOMO Services Catalog* (Reference 1). These services support both Earth orbiting and deep space science missions. Table 1-1 summarizes SOMO service categories.

**Table 1-1: SOMO Service Categories**

| SOMO Service Category | Brief Description |
|---|---|
| Command | RF modulation, transmission, and delivery of telecommands to spacecraft. |
| Telemetry | Telemetry data capture and additional value-added data routing and processing. |
| Mission Data Management | Data buffering, staging, storing, and archiving. |
| Experiment Data Products | Higher level data processing providing photo and science visualization products. |
| Tracking and Navigation | Radio metric data capture and generation of high order navigation products. |
| Telecom Analysis | Spacecraft link performance, analysis, and prediction. |
| S/C Time Correlation | Monitors spacecraft clock drift and correlates time to a standard time reference. |
| Mission Control | Monitors spacecraft health and safety and sends corrective commands. |
| Instrument Control | Monitors specific spacecraft instruments, sends corrective commands. |
| Flight Engineering | Performance analysis and anomaly detection of instrument and S/C systems. |
| Radio Science | S/C Doppler, range, and open-loop receiver measurements at 2, 8, and 32 GHz. |
| VLBI | Capture of narrowband or wideband very long baseline interferometric data. |
| Radio Astronomy | Similar to Radio Science except measures natural phenomena. |
| Service Management | Planning, scheduling controlling, configuring and accounting of system resources. |
| Mission Planning | Trajectory and mission design, launch analysis, science instrument planning. |
| Sequence Engineering | Uplink process and sequence design, S/C operations schedule, event prediction. |
| Ground Communications | Data, voice, and video communications network services. |

### 1.5 Process for Requesting Services

Proposers should contact SOMO officials for information on NASA's mission operations services and costs at the time when initial science operations concepts are being defined. A SOMO representative will provide information on SOMO services and costs, and will assist in documenting initial mission operations requirements in a format termed a "Service Request". During the concept study phase, as the proposer's mission concept becomes more clearly defined, the requirements in the Service Request will be clarified. The resulting documentation of services and costs will become a "Project Service Level Agreement (PSLA)" to be signed by a SOMO representative and the proposer. The PSLA will identify all mission operations requirements, even those provided by non-SOMO sources, to provide a source of end-to-end operations information and to document any cost analyses leading to the selection of non-SOMO services.

The primary SOMO point of contact for this AO is the SOMO Lead Center Customer Commitments Manager (CCCM) for the Discovery missions::

Douglas G. Griffith
Deputy Manager, Plans and Commitments Office 920
Telecommunications and Mission Operations Directorate (TMOD)
Jet Propulsion Laboratory
M/S 303-402
4800 Oak Grove Drive
Pasadena, California 91109
Phone: (818) 393-3970
e-mail: douglas.g.griffith@jpl.nasa.gov

For information about NASA's overall mission operations and communications services, contact:

John Dalton
SOMO Mission Services Manager
Code 720
Goddard Space Flight Center
Greenbelt MD 20771
Phone: (301) 286-7213
Fax number: (301) 286-1765
e-mail: john.dalton@gsfc.nasa.gov

## 1.6 Standards

It is NASA policy that space missions receiving funding from NASA comply with all international and United States regulations, standards, and agreements. Such regulations and standards include those promulgated by:

International Telecommunications Union (ITU)
National Telecommunications and Information Agency (NTIA)
Consultative Committee for Space Data Systems (CCSDS)
Space Frequency Coordination Group (SFCG)

Information about the ITU and NTIA, regulations can be obtained from NASA's Spectrum Management Office at the Glenn Research Center or by consulting References 2 and 3. Recommended CCSDS standards applicable to DSN, Ground Network, or TDRSS support can be obtained from Reference 4, the CCSDS home page. Recommendations of the SFCG are available in Reference 5.

Flight missions wishing to employ the DSN should consider these standards:

### 1.6.1 TMOD Services Interface

Institutions wishing to transfer data to or from TMOD facilities should utilize a standard *Space Link Extension* (SLE) *Services Interface*. The interface has been designed to promote the interoperability of mission control centers with the DSN as well as several other large-aperature ground stations operated (or in planning) by other international space organizations. The interface's architecture is based upon internationally adopted standards promulgated by the CCSDS. It will become operational on or before 1 January 2001 and missions launching after that date should plan to use this system.

### 1.6.2 X-Band and $k_A$-Band Communications

Projects operating in a *Space Research* allocation, which launch after 2003, should be designed to communicate in either the 7/8 GHz or 7/32 GHz bands. Both deep space and near Earth allocations exist in the 7/8 GHz band and should be used by future missions. Ever increasing congestion and the addition of allocations for incompatible services (e.g., IMT-2000) have made future operations in the 2 GHz band uncertain and, therefore, risky. As such the Office of Space Science is recommending against the use of the 2 GHz band for future missions.

### 1.6.3 Use of File Transfer Protocols

To improve DSN station utilization efficiency, all DSN users should use the CCSDS File Transfer Protocol (FTP), known as CFDP, to download telemetry data from their spacecraft to Earth.

### 1.7 DSN Loading Studies

Those proposals choosing to employ the DSN <u>and</u> which are selected for the concept study should work with JPL/TMOD in order to assess the schedule load which the proposed investigation will impose on the DSN. The results of this assessment should be included in the concept study report.

## 2.0 Costs of Using the Deep Space Network

Most proposed Discovery missions will operate in deep space which forces missions to operate with restricted communications bandwidths as compared to missions orbiting close to Earth. In developing their mission concept, proposers usually perform trade-offs among the elements of the end-to-end data system. The elements include instrument format design, flight data system, the space communications features, and the several elements of the ground data system. The integrated contact time and the contact frequency of the spacecraft with the DSN are typically important parameters in these trade studies.

To facilitate these trade studies, the following sections present the cost algorithm for employing the DSN.

### 2.1 Deep Space Network

The DSN consists of control, communications, and test facilities at JPL, and Earth station complexes located near Goldstone, California; Canberra, Australia; and Madrid, Spain. The DSN provides communications services between spacecraft and Earth station complexes together with the ground communications among the complexes and the DSN control center located at JPL in Pasadena, California.

Testing to establish compatibility between the spacecraft's Radio Frequency Subsystem (RFS) and DSN stations is available at the Development Test Facility (DTF-21) at JPL in Pasadena or by using the Compatibility Test Trailer (CTT) at a remote site. RFS compatibility testing is highly recommended and should be completed about one year prior to launch.

The DSN 26-meter, 34-meter, and 70-meter diameter antennas operating in the 2, 7, 8, and 32 GHz bands provide radio frequency communications. User costs vary with aperture size and utilization level. Generally, DSN services are included in the *Aperture Fee* (see Equation 2-1 below).

The DSN 11-meter stations are designed for space-based very long baseline interferometry (SVLBI) and operate at 7, 8, and 15 GHz. SVLBI missions are characterized by high data rates and nearly continuous Earth station support requirements. Because of their limited capability, 11-meter stations are priced at a flat rate.

Reference 6 contains a general description as well as the specific characteristics of the DSN.

## 2.2 DSN Antenna Fees

***Cost numbers supplied in this Section are for planning purposes only. To ensure accurate application of this information and to validate cost estimates please contact the TMOD representative listed in Section 1.5. TMOD costs in Phase 2 proposals should always be validated by TMOD.***

The algorithm for computing DSN *Aperture Fees* embodies incentives to maximize DSN utilization efficiency. It employs *weighted hours* to determine the cost of DSN support. The following equation can be used to calculate the *hourly Aperture Fee* (AF) for DSN support.

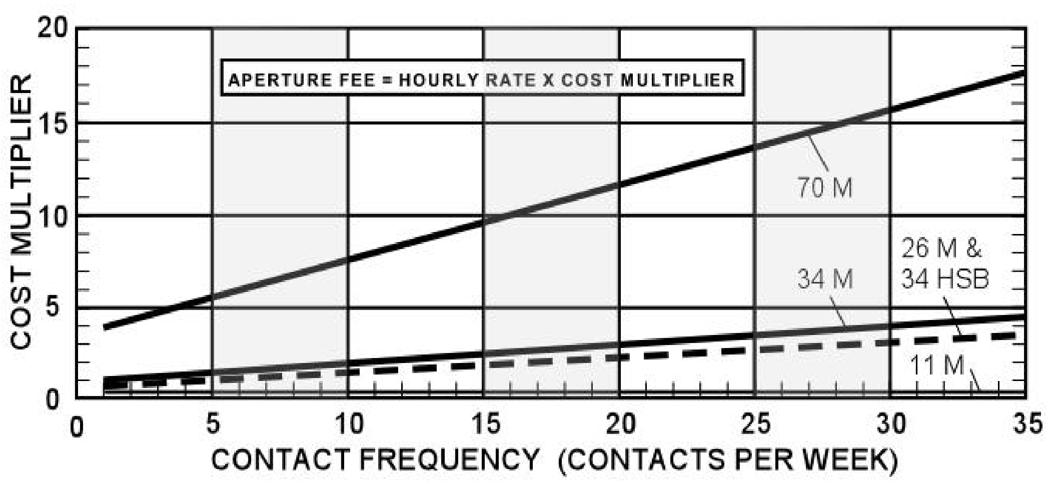
$$AF = R_B\, [A_W\, (0.9 + F_C\ /\ 10)] \qquad (2\text{-}1)$$

where:

AF = weighted *Aperture Fee* per hour of use.
$R_B$ = contact dependent hourly rate, adjusted annually ($708/hr. for FY00).
$A_W$ = aperture weighting:
= 0.80 for 26-meter or 34-meter High-Speed Beam Waveguide (HSB) stations.
= 1.00 for all other 34-meter stations (i.e., 34BWG and 34 HEF).
= 4.00 for 70-meter stations.
$F_C$ = number of station contacts, (contacts per calendar week).

The *weighting factor* graph below shows relative antenna costs. It graphically illustrates the cost relationships between antennas and demonstrates the benefits of restricting the number of spacecraft-Earth station contacts each week.

A *station contact* may be any length but is defined as the lesser of the spacecraft's viewperiod, the scheduled pass duration plus calibration times, or 12 hours. A 45-minute precalibration and a 15-minute post calibration time must be added to each scheduled pass to obtain the *station contact* time.



Total DSN cost is obtained by partitioning mission into calendar weeks and summing the *Aperture Fees*. This total cost can be obtained by grouping weeks having the same requirement in the same year, multiplying by weighted *Aperture Fee*, and summing over the mission's duration.

## 2.3 Multiple Spacecraft Supported by a Single Antenna - Fee Reduction

Some flight programs, such as those surveying Mars, cluster several spacecraft about a planetary location. It is possible to simultaneously capture telemetry signals from two or more spacecraft provided that they lie within the beamwidth of an Earth station's antenna.

There are a few constraints. First, only a single uplink frequency can be transmitted. In most cases, this means that only one spacecraft in the cluster can operate in the two-way coherent mode. The remainder must be in a one-way mode. Second, multiple, independent receivers are required at the Earth station. This sets a practical limit on the number of spacecraft that can be served simultaneously to 4. Third, ranging and two-way coherent Doppler data can only be obtained from the single spacecraft in a two-way mode.

If this situation applies and the constraints are acceptable, then it may be possible to reduce the Antenna cost for all spacecraft operating in this mode. To calculate the cost, first compute the *Aperture Fee* using equation 2-1 above. Thereafter, apply the correction factor according to the formula:

$$AF' = (0.75)\ AF \qquad (2\text{-}2)$$

where:

AF' = weighted *Aperture Fee* per hour of use when 2 or more spacecraft simultaneously share the same antenna.

The reduced price, AF', reflects the reduced capability available as a result of sharing. It assumes that the uplink and ranging capabilities will rotate through all spacecraft on a substantially equal basis.

## 2.4 Compatibility Testing Cost

TMOD encourages prelaunch compatibility testing as a means to eliminate post launch anomalies and expensive troubleshooting. TMOD maintains a facility known as the Development Test Facility (DTF-21) in Pasadena, California. Except for the high power transmitter and low noise-receiving amplifier, which are not included, DTF-21 is configured much like an operational DSN Earth station.

Approximately one year prior to launch, projects should to bring their Radio Frequency Subsystems (RFS) to DTF-21 for testing. Testing requires approximately two weeks and includes such items as RF compatibility, data flow tests, and transponder calibration.

Because TMOD believes that this testing materially improves the likelihood of success, no charge is made for the use of these facilities for a single set of compatibility tests. Rather, it is included in the hourly-dependent rate, $R_B$, used in Equation 2-1.

## 2.5 Cost Calculations

DSN costs (*Aperture Fee , AF in $/Hr.*) can be calculated by selecting a specific antenna and then determining the number and duration of tracking passes required to satisfy project navigation and science objectives. Each tracking pass must be increased in length by 45 minutes for calibrations. Once the pass length and number of passes is determined, multiply the aggregate hours by the hourly *Aperture Fee* computed using equation (2-1). A reduced cost is available when two or more spacecraft simultaneously share the same antenna (equation 2-2).

As a minimum, proposals should contain the set of telecommunications parameters in Table 2-1. While proposers may or may not wish to use a tabular format, the required parameter values should be supplied in a clear, concise, and readily apparent form. Table 2-2 is an example of such a form containing 20 parameter values in only 1/3 of a page.

A form, entitled Table 2-3: *DSN Mission Support Costs*, can be used to tabulate DSN *Aperture Fees*. A personal computer program, running under Excel 97/98, is available to assist in preparation of the cost estimates. See Section 1.5 for the TMOD point of contact.

The 11-meter station is charged at a flat rate of $0.2R_B$ irrespective of the number of hours that they are used each week.

## Table 2-1: Telecommunications Parameters and Definitions

| Parameter | Units | Description |
|---|---|---|
| Maximum S/C Distance | Km | Maximum spacecraft-earth station distance during primary mission. |
| Encounter 1 Distance | Km | Maximum spacecraft-earth station distance during first encounter. |
| Encounter 2 Distance | Km | Maximum spacecraft-earth station distance during second encounter. |
| Encounter N Distance | Km | Maximum spacecraft-earth station distance during Nth encounter. |
| Uplink Transmitter Power | Watts | Earth Station Transmitter Output. |
| Uplink Frequency Band | GHz | Proposed earth-to-space frequency band expressed in GHz. |
| Uplink Transmitting Antenna | DBi | Gain (or name) of earth stations transmitting antenna (e.g., 34M BWG). |
| S/C Receiving Antenna Gains | DBi | Gains of all spacecraft receiving antennas. |
| Telecommand Data Rate | b/s | Maximum desired telecommand data rate. |
| Telecommand Bit-Error-Rate | - | Required telecommand Bit-Error-Rate (BER). |
| S/C Receiver Bandwidth | Hz | S/C Receiver's phase-locked-loop threshold bandwidth (2 Blo). |
| Turnaround Ranging | Yes/No | Statement whether turnaround ranging is required. |
| SC Transmitting Power | Watts | S/C Power amplifier Output. |
| Downlink Modulation Format | Name | Format name (e.g., PCM/PM/Bi-Ù, PCM/PSK/PM, BPSK, QPSK, etc.). |
| Downlink Frequency Band | GHz | Proposed space-to-earth frequency band expressed in GHz. |
| S/C Transmitting Antenna | DBi | Gains of all spacecraft transmitting antennas. |
| Downlink Receiving Antenna | DBi | Gain (or name) of earth station receiving antenna (e.g., 34M BWG) . |
| Telemetry Data Rate | b/s | Maximum desired telemetry data rate. |
| Telemetry Coding | Name | Telemetry code (e.g., convolutional, Reed-Solomon, concatenated, etc.). |
| Telemetry Bit-Error-Rate | - | Required telemetry Bit-Error-Rate (BER). |

## Table 2-2: Sample Table for Inclusion in Proposal

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Maximum S/C Distance (km) | | S/C Receiver Bandwidth (Hz) | |
| Encounter 1 Distance (km) | | Turnaround Ranging (Yes/No) | |
| Encounter 2 Distance (km) | | S/C Transmitting Power (Watts) | |
| Encounter N Distance (km) | | Downlink Modulation Format (Name(s)) | |
| Uplink Transmitter Power (Watts) | | Downlink Frequency Band (GHz) | |
| Uplink Frequency Band (GHz) | | S/C Transmitting Antenna Gains (dBi) | |
| Uplink Transmitting Antenna Gains (dBi) | | Downlink Receiving Antenna Gain (dBi) | |
| S/C Receiving Antenna Gains (dBi) | | Telemetry Data Rate (b/s) | |
| Telecommand Data Rate (b/s) | | Error Detecting-Correcting Code (Name) | |
| Telecommand Bit-Error-Rate | | Telemetry Bit-Error-Rate | |

| | |
|---|---|
| Mission Name: | |
| Program Name: | |
| Launch Year: | |
| User Type: | |
| Prepared By: | |
| Date Prepared: | |

| DSN SUPPORT SUMMARY | |
|---|---|
| Total Station Cost: | |
| TMS Manager Cost: | |
| NOPE Cost: | |
| Total DSN Hours: | |
| Total Support Cost: | |

| | Mission Phase | Antenna Size (meters) | Service Year (year) | Hours per Track (hours) | No. Tracks per Week (# tracks) | No. Weeks Required (# weeks) | Total Pre-Cal. (hours) | Total Post-Cal. (hours) | Total Time Reqd. (hours) | Total Cost for period (real-year $) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | | | | | | | | | |
| 8 | | | | | | | | | | |
| 9 | | | | | | | | | | |
| 10 | | | | | | | | | | |
| 11 | | | | | | | | | | |
| 12 | | | | | | | | | | |
| 13 | | | | | | | | | | |
| 14 | | | | | | | | | | |
| 15 | | | | | | | | | | |
| 16 | | | | | | | | | | |
| 17 | | | | | | | | | | |
| 18 | | | | | | | | | | |
| 19 | | | | | | | | | | |
| 20 | | | | | | | | | | |
| 21 | | | | | | | | | | |
| 22 | | | | | | | | | | |
| 23 | | | | | | | | | | |
| 24 | | | | | | | | | | |
| 25 | | | | | | | | | | |
| 26 | | | | | | | | | | |
| 27 | | | | | | | | | | |
| 28 | | | | | | | | | | |
| 29 | | | | | | | | | | |
| 30 | | | | | | | | | | |

| Service Description | Year of Service | TMS Manager | | NOPE | |
|---|---|---|---|---|---|
| | | Work-Yrs | Cost ($K) | Work-Yrs | Cost ($K) |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Total: | | | | | |

**Instructions**

1. Complete summary table in upper left hand corner.
   a. Specify *Launch Year* as 4-digits (e.g., 2002).
2. In main table above, each line must:
   a. Specify DSN antenna size (e.g., 11, 26, 34, 70).
      1) Specify 34M as either 34BWG or 34HEF subnet.
   b. Name a single year using 4-digits (e.g., 2002).
      1) Only one year permitted one each line.
   c. Contain same level of support requirements.
3. Calibration times added to each pass automatically.
   a. Pre-Cal. = 30 minutes; Post-cal. = 15 minutes.
4. All costs computed in real-year dollars.
   a. Costs automatically inflated at official NASA Hq. rate.
5. Enter TMS Mgr. & NOPE WY requirements in table to left.
   a. TMS Mgr. & NOPE costs computed in real-year dollars.
6. Summary of total costs appear in table at upper right.
7. Only Government missions handled at this time.

**Table 2-3: Form for estimating DSN mission support costs**

## 2.6 Advanced Multi-Mission Operations System

AMMOS offers users a selection of services and tools for spacecraft command and control, data reduction and analysis, and navigation. TMOD services are integrated, and certain DSN services may be a prerequisite to obtaining AMMOS value-added services. The main AMMOS elements are located at JPL; however, specific subsystems may also be placed at user sites. Proposals should identify specific AMMOS services listed in Reference 7 required for mission support and the costs for each service over the life of the mission.

In addition to its standard services, AMMOS can provide users with specific software tools. Such tools include telecommand encapsulation and protocol verification, mission analysis software, spacecraft monitoring programs, and data analysis software.

Because each mission is unique, it is difficult to provide a priori tool prices. Generally, AMMOS personnel need to confer with cognizant project personnel to determine specific tool requirements. Thereafter, it should be possible to quote a price for the product. If a tool's specification can be completed by the end of Phase B, work can commence at the start of Phase C/D so that the tool will be available at launch.

For more information on AMMOS tools and services, proposers are encouraged to contact:

Greg J. Kazz
Telecommunications and Mission Operations Directorate (TMOD)
Jet Propulsion Laboratory
M/S 303-402
4800 Oak Grove Drive
Pasadena, California 91109
Phone: (818) 393-6529
Email: greg.j.kazz@jpl.nasa.gov

## 3.0 REFERENCES

Prospective users of SOMO and TMOD facilities can obtain additional information from the following documents:


1. *SOMO Services Catalog*, NASA Space Operations Management Office, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, Code TA, 2101 NASA Road 1, Houston, Texas 77058. ***Copies of the document are available at:*** http://www.jsc.nasa.gov/somo/.

2. *Radio Regulations*, International Telecommunications Union, Geneva, Switzerland.

**3.** *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications & Information Administration, U.S. Department of Commerce, Washington D.C., Latest Edition. **Information is available at:** http://www.ntia.doc.gov/osmhome/redbook/redbook.html

4. Consultative Committee for Space Data Systems (CCSDS). Blue Books published by the CCSDS Secretariat, NASA Headquarters, Washington D. C. 20546. ***Copies of CCSDS Recommendations are available at:*** http://www.ccsds.org/blue_books.html.. *CCSDS CFDP information is available at:* http://www.ccsds.org/red_books.html.

5. *Handbook of the Space Frequency Coordination Group*, ESA Frequency Manager and SFCG Secretariat, European Space Agency Headquarters, 8-10 Rue Mario Nikis, 75738 Paris, France. ***Copies of the document are available at:*** http://sfcg.lerc.nasa.gov/

6. *TMOD's Mission Operations and Communications Services (A Handbook for Preparing Proposals)*, Telecommunications and Mission Operations Directorate, Jet Propulsion Laboratory, Pasadena, California, **Latest Edition**. ***Copies of the document are available at***: http://deepspace.jpl.nasa.gov/advmiss

7. *Telecommunications and Mission Operations Directorate Services Catalog*, Organization 920, Jet Propulsion Laboratory, Pasadena, California, V 6.0 (or later edition), September 1998. http://jpl-madb.jpl.nasa.gov/srp/catalogHTML/CATALOG-FS.htm